Chemical Process Safety

Chapter 9: Relief Systems
Chapter 9: Learning Objectives

1. Understand the importance of pressure protection.
2. Understand runaway reactions.
3. Understand the relief design procedure.
4. Understand the definitions related to relief systems.
5. Understand 2-phase flow and how that relates to relief sizing.
6. Understand the various types of relief devices and their advantages and disadvantages.
7. Understand the design, installation and maintenance issues with relief systems.
8. Be able to specify where relief devices are required.
9. Be able to specify relief scenarios.
Introduction

What: A relief system protects the process from the damaging effects of high or low pressure.

How: A relief system removes energy from a process by discharging mass with an energy content.
How Can High Pressures Develop?
Relief Design Procedure

1. Locate Reliefs
2. Choose Relief Types
3. Define Scenarios
4. Acquire Data:
   * Physical Props.
   * Self Heat Rate
   * Others

Choose Worst Case
Design Relief System

Figure 9-1

Options:
- Single Phase
- Two Phase
Definitions - 1

Set Pressure: Pressure at which the relief device begins to open.

Maximum Allowable Working Pressure (MAWP): Maximum design pressure at the top of a vessel for a designated temperature.

As T increases,

As T decreases,

Vessel fails at time MAWP.
Overpressure: Pressure increase over set pressure during relieving. Expressed as % of set pressure. Must be specified prior to relief design. Typically 10%
Accumulation: The pressure increase over the MAWP of the vessel during the relief process. Expressed as % of MAWP.
Backpressure: The pressure downstream of the relief device during the relieving process.

Must be considered in any relief system design.

Two types of backpressure:

1. Superimposed
2. Built-up
Backpressure - Superimposed

- Pressure in discharge header before valve opens
- Can be constant or variable
Backpressure – Built-up

- Pressure in discharge header due to frictional losses after valve opens

\[ \text{Total Backpressure} = \text{Superimposed} + \text{Built-up} \]
Normal PRV has definite pop and reseat pressures.

These two pressures can be noted on a gauge as shown.

\[ \text{Blowdown} = \text{Difference between pop and reseat pressure} \]
Spring-loaded Reliefs

Set pressure and flow affected by back pressure:
- Set pressure $\propto (P_{PROCESS} - P_{DOWNSTREAM})$
- Flow $\propto (P_{PROCESS} - P_{DOWNSTREAM})$

Set pressure increases
Flow decreases

Fig. 9-7
Spring-loaded Reliefs
Spring-loaded Reliefs

- Set Pressure Adjusting Screw
- Spring
- Bonnet
- Disc Holder
- Seat Disc
- Blowdown Adjustment Ring
- Nozzle
Spring-Loaded Relief Installed on Vessel
Spring-Loaded Relief Installed in Plant
Advantages / Disadvantages
Conventional Valve

• **Advantages**
  + Most reliable type if properly sized and operated
  + Versatile -- can be used in many services

• **Disadvantages**
  – Relieving pressure affected by back pressure
  – Susceptible to chatter if built-up back pressure is too high
Spring-loaded Reliefs

- Setpressure $\propto (P_{\text{PROCESS}} - P_{\text{AMBIENT}})$
- Flow $\propto (P_{\text{PROCESS}} - P_{\text{DOWNSTREAM}})$
- Setpressure not affected by backpressure.
- Flow decreases with backpressure.
BALANCED BELLOWS

BONNET VENT

BELLOWS
Advantages / Disadvantages
Balanced Bellows Valve

• Advantages
  + Relieving pressure not affected by back pressure
  + Can handle higher built-up back pressure
  + Protects spring from corrosion

• Disadvantages
  – Bellows susceptible to fatigue/rupture
  – Flow thru valve is affected by back pressure
Balanced Bellows PRV
Chatter

• Chattering is the rapid, alternating opening and closing of a PR Valve.

• Resulting vibration may cause misalignment, valve seat damage and, if prolonged, can cause mechanical failure of valve internals and associated piping.

• Chatter may occur in either liquid or vapor services
Chatter - Principal Causes

- Excessive inlet pressure drop
- Excessive built-up back pressure
- Oversized valve
- Valve handling widely differing rates
Chatter Mechanism
Excessive Inlet Pressure Drop
Undersized inlet piping
Consider the pressure drop from all these connections.
Rupture Discs

• A rupture disc is a thin diaphragm (generally a solid metal disc) designed to rupture (or burst) at a designated pressure. It is used as a weak element to protect vessels and piping against excessive pressure (positive or negative).

• There are five major types available
  – Conventional tension-loaded rupture disc
  – Pre-scored tension-loaded rupture disc
  – Composite rupture disc
  – Reverse buckling rupture disc with knife blades
  – Pre-scored reverse buckling rupture disc
Rupture Discs

• They are often used as the primary pressure relief device.
  – Very rapid pressure rise situations like runaway reactions.
  – When pressure relief valve cannot respond quick enough.

• They can also be used in conjunction with a pressure relief valve to:
  – Provide corrosion protection for the PRV.
  – Prevent loss of toxic or expensive process materials.
  – Reduce fugitive emissions to meet environmental requirements.
Rupture Disk

* Calibrated metal disk
* Remains open after rupture
* Subject to pressure cycling fatigue
Rupture Disk
Rupture Disk
Rupture Discs Are Well Suited For Some Applications

Advantages

+ Reduced fugitive emissions - no simmering or leakage prior to bursting.
+ Protect against rapid pressure rise cased by heat exchanger tube ruptures or internal deflagrations.
+ Less expensive to provide corrosion resistance.
+ Less tendency to foul or plug.
+ Provide secondary protective device for lower probability contingencies requiring large relief areas.
Rupture Discs Are Less Well Suited For Other Applications

Disadvantages

- Don’t reclose after relief.
- Burst pressure cannot be tested.
- Require periodic replacement.
- Greater sensitivity to mechanical damage.
- Greater sensitivity to temperature.
- Sensitive to pressure cycling causing metal fatigue.
Disc Corroded Through
Damaged during Installation
Alligatoring is caused by operating too close to the set pressure.
Rupture Disk

Tell-tale pressure gauge

Protects spring device against corrosion, plugging.

Protects spring reliefs: corrosion, plugging

Absolute protection, no weeping: toxicants, flammables

Problem: Piece of rupture disk might break off and plug spring relief
Piston Type Pilot Operated Safety Relief Valve

Upper surface is larger, causing a greater downward pressure.
Piston Type Pilot Operated PRV
Advantages / Disadvantages
Pilot Operated Valve

• **Advantages**
  + Relieving pressure not affected by backpressure
  + Can operate at up to 98% of set pressure
  + Less susceptible to chatter (some models)

• **Disadvantages**
  – Pilot is susceptible to plugging
  – Limited chemical and high temperature use by “O-ring” seals
  – Vapor condensation and liquid accumulation above the piston may cause problems
  – Potential for back flow
Rupture Pins

- A rupture pin is designed to be a non-reclosing pressure relief device, similar to a rupture disc.
- A piston is held in the closed position with a buckling pin which will fail at a set pressure according to Euler's Law.
- An o-ring on the piston is used to make a bubble tight seal.
Conventional Rupture Pin Device
Comparison of Rupture Pins To Rupture Discs

**Advantages**

+ Not subject to premature failure due to fatigue
+ Can be operated closer to its set point
+ Setpoint is insensitive to operating temperature
+ Available as balanced or unbalanced device
+ Capable of operating as low as 0.1 psig (0.007 barg)
+ Suitable for liquid service
+ Resetting after release usually requires no breaking of flanges
+ Replacement pins are 1/3 to 1/4 the cost of replacement discs
Comparison of Rupture Pins To Rupture Discs

Disadvantages

- The elastomer o-ring seal limits the maximum operating temperature to about 450°F (230°C)

- Initial cost of installation is greater than for a rupture disc
  * twice as costly for 2” carbon steel
  * up to seven times as costly for 8” stainless steel
Figure 9-4

Definitions

PRESSURE VESSEL

- Maximum allowable working pressure
- Max. operating pressure
- Maximum allowable accum. pressure

TYPICAL RELIEF VALVE

- Max. relieving pressure - fire
- Max. relieving pressure
- Max. set pressure
- Reseat pressure
- Leak test
Relieving pressure shall not exceed MAWP (accumulation) by more than:

- 3% for fired and unfired steam boilers
- 10% for vessels equipped with a single pressure relief device
- 16% for vessels equipped with multiple pressure relief devices
- 21% for fire contingency
Discharge directed downward
Discharge too near deck
Long moment arm
Will these bolts hold when the PRV relieves?
Bellows plugged in spite of sign
Runaway Reactions - 1

Why important: Common problem with exothermic reactions.
Runaway Reactions - 2

How?

1. Loss of coolant.
2. Increased temperature.
3. Increased energy generation.

High pressure due to: Vapor pressure of liquid.
Vapor decomposition products.

Larger vessels respond faster - less heat transfer thru walls!!!

Some chemicals can achieve self heat rates of 100’s deg. C/min! Styrene, Acrylic Acid
Runaway Reactions - 3

Some ways for runaways to occur:

- Loss of cooling.
- Overcharge reactant.
- External fire.
- Mis-charge reactant.
- Low reaction temperature in semi-batch reactor. This is called a sleeping reactor.
- Loss of agitation.

Most reactive runaways result in 2-phase flow thru relief and require a relief area 2 to 10 times larger than single phase relief.
Runaway Reactions - 4
Table 9-1 Relief Locations

- All process and storage vessels.
- Pumps (positive displacement), compressors, turbines. Many have internal reliefs.
- Blocked, liquid-filled lines.
- Jackets on vessels.
- Others

<table>
<thead>
<tr>
<th>Cooling Water</th>
<th>Hot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valves closed</td>
<td>Valves closed</td>
</tr>
</tbody>
</table>
Relief Locations:

1.
2.
3.
4.
Relief Scenarios

**What:** Describe situations or sequences of events that result in high pressure.

- Could be dozens of scenarios for a particular piece of equipment, particularly with reactors.
- Select worst case, i.e. case that requires largest relief area.

**Generally, worst case is:**

- Runaway Reaction.
- External Fire.
Relief Scenarios - Example

High Pressure In Reactor

1.
2.
3.
4.
5.
THE END

“THINK SAFETY”!